Operational Status, Plans and Modeling in FY04
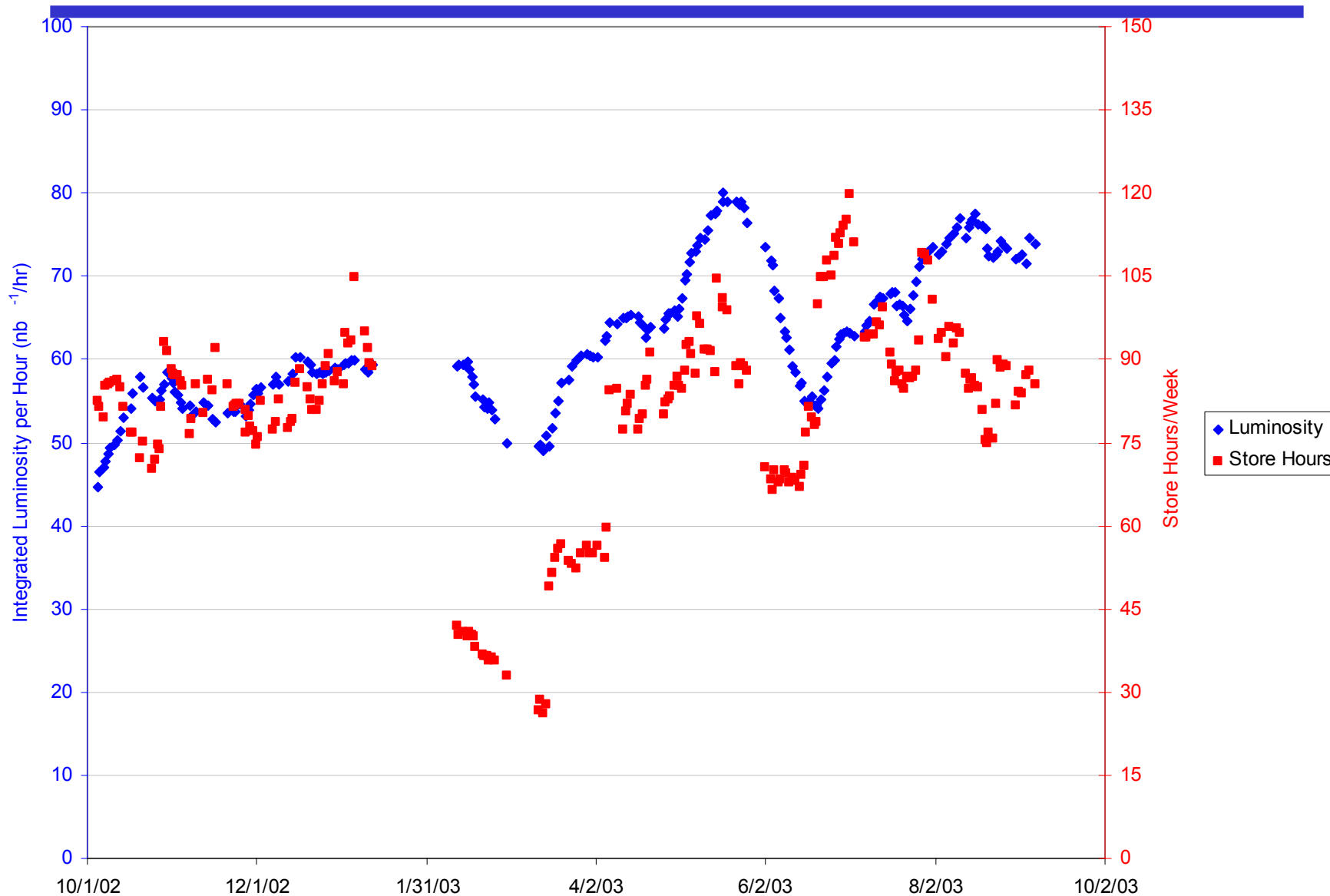
DOE Review

October 8, 2003

Dave McGinnis

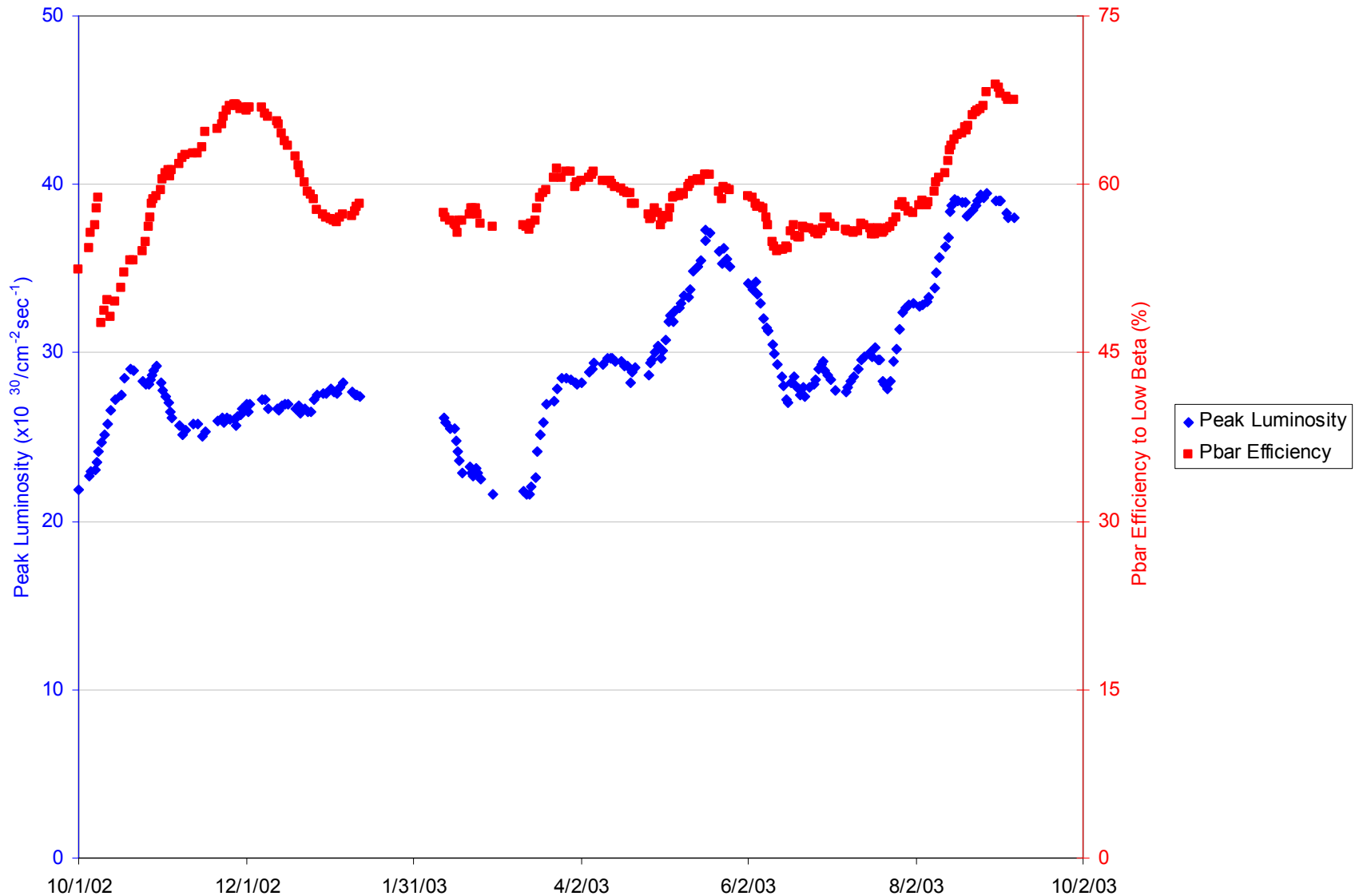# Outline

- **FY03 Performance**
- **Accelerator Issues**
  - TEV
  - Pbar
  - Main Injector
  - Reliability
- **Operations**
  - Study Strategy
  - Shot Strategy
- **FY04 Luminosity Parameters**
- **Summary**

FY03 Performance

FY03 Performance

FY03 Performance

FY03 Performance

Parameter	Last Store	Last 10 stores Average	Last 10 stores St. Dev.	Last 50 stores Average	Last 50 stores St. Dev.	
Initial Luminosity (Average)	40.2	37.5	4.6	36.1	6.5	$\times 10^{30} cm^{-2} sec^{-1}$
Integrated Luminosity per Store (Averaged)	1510.3	1053.0	396.9	1088.9	495.7	nb^{-1}
Luminosity per week (Averaged)	-	5.6	-	6.4	-	pb^{-1}
Store Length	19.9	14.1	5.4	14.9	6.7	Hours
Store Hours per week	-	75.5	-	87.8	-	Hours
Shot Setup Time	2.5	2.2	0.3	2.3	0.6	Hours
Protons per bunch	238.2	237.3	22.6	237.3	18.8	$\times 10^9$
Proton Efficiency to Low Beta	58.0	59.9	3.4	58.3	4.7	%
Antiprotons per bunch	22.6	22.5	3.0	22.2	2.6	$\times 10^9$
Start Stack	118.8	134.6	26.5	144.3	22.1	$\times 10^{10}$
End Stack	11.8	14.8	5.4	16.5	11.0	$\times 10^{10}$
Unstacked Pbars	107.0	119.8	24.0	128.2	19.6	$\times 10^{10}$
Pbar Transfer efficiency to Low Beta	76.0	68.5	6.3	63.3	7.7	%
HourGlass Factor	0.63	0.64	0.01	0.63	0.01	

FY03 Performance

Efficiency	Last Store	Last 10 stores Average	Last 10 stores St. Dev.	Last 50 stores Average	Last 50 stores St. Dev.	
MI Injection (Pbar)	98.0	97.0	0.7	95.8	3.8	%
MI Acceleration (Pbar)	98.0	99.1	0.6	98.8	0.8	%
Coalescing (Pbar)	95.0	92.8	2.6	92.4	3.2	%
Tev Injection (Pbar)	93.0	91.4	1.0	89.8	2.0	%
TEVAcceleration (Pbar)	96.0	93.5	3.7	91.1	4.8	%
Initiate Collisions (Pbar)	96.0	94.4	2.1	92.0	5.7	%
Unaccounted (Pbar)	97.2	95.1	5.9	95.9	10.0	%
Efficiency	Last Store	Last 10 stores Average	Last 10 stores St. Dev.	Last 50 stores Average	Last 50 stores St. Dev.	
MI Injection (Proton)	90.0	91.4	4.2	91.7	3.8	%
MI Acceleration (Proton)	94.0	98.2	2.2	96.5	13.9	%
Coalescing (Proton)	90.0	88.6	3.5	87.4	3.0	%
Tev Injection (Proton)	94.0	95.1	2.0	94.1	2.0	%
TEVAcceleration (Proton)	93.0	95.2	1.5	95.1	1.2	%
Unnacounted (Proton)	87.1	83.3	2.0	81.7	5.2	%

Accelerator Issues

Run II (without the Recycler) and Run Ib

- Projected - 5.3x (8.5×10^{31} cm^{-2} sec^{-1} / 1.6×10^{31} cm^{-2} sec^{-1})
- Delivered – 2.3x (3.7×10^{31} cm^{-2} sec^{-1} / 1.6×10^{31} cm^{-2} sec^{-1})
- More Pbars
  - projected - 3.3x
    - More protons on target - 2x (5×10^{12}/2.5×10^{12})
    - Faster Pbar cycle rate - 1.6x (2.4sec/1.5sec)
  - delivered - 1.9x
    - More protons on target - 1.9x (4.7×10^{12}/2.5×10^{12})
    - Faster Pbar cycle rate - 1x (2.4sec/2.4sec)
- More Protons
  - projected - 1.17x (270×10^{9}/230×10^{9})
  - delivered – 1.09x (250×10^{9}/230×10^{9})
- Shorter Bunch lengths
  - projected form factor - 1.25x (0.37m <- 0.6 m)
  - delivered form factor – 1.07x (0.52m <- 0.6 m)
- Higher Energy
  - projected – 1.11x (1000 GeV/ 900 GeV)
  - delivered – 1.09x (980 GeV/ 900 GeV)

TEVATRON Issues

- Transverse Emittance Dilution at injection
  - Transmission efficiency to low beta
  - Long range Beam Beam effects – big beam sizes
- Chromaticity control
  - Lifetime at 150 GeV
  - Stability – number of protons at low beta
- Helices
  - Transmission efficiency to low beta
  - Long range Beam Beam effects
- Reliability

TEVATRON Transmission Efficiency

- We made very good progress during the summer of 2003 in increasing the efficiency from 60% to 73% (SBD corrected)
  - ➤ S6 circuits and differential chromaticity
  - ➤ New high energy helix
  - ➤ Accumulator to MI pbar emittance reduction
  - ➤ TEV injection lattice corrections
- At first glance, 73% antiproton transmission efficiency from the Accumulator Core to Low Beta seems to be very low.
- However, the 73% transmission efficiency is composed of many stages of transfers each with relatively good efficiency $73\% = (94\%)^5$
- To improve the transfer efficiency to 90%, the average efficiency of each stage of the pbar transfer must increase from 94% to 98%
- Increasing the pbar transfer efficiency from 73% to 90% will increase the luminosity by a factor of 1.23

TEVATRON Projects

- Transverse Emittance Dilution at injection
  - ➢ Injection lattice matching for pbars and protons
  - ➢ Smart bolt retro-fit to be (this shutdown)
  - ➢ New TEVATRON sextupole (borrowed from Pbar)
  - ➢ Injection dampers for pbars
- TEVATRON Chromaticity Control
  - ➢ Shielding of the F0 Lambertsons
  - ➢ Re-wiring of the TEV octupole circuits
- Better TEV Helices
  - ➢ Optimized helices at 150 GeV
  - ➢ TEV alignment

Emittance dilution at Injection into the TEV

- **Injection lattice matching for pbars and protons**
  - First pass complete
  - Second pass study time completed
    - Will require new optics for 150 GeV injection lines
  - First pass at TEV injection lattice corrections completed
- **Remove coupling**
  - Smart bolt retro-fit to be (this shutdown)
  - New TEVATRON sextupole (borrowed from Pbar)
    - Decoupling injection helical orbits
- **Injection dampers for pbars**
  - Already installed in early FY04
  - await more commissioning time

TEVATRON Issues

- ## TEVATRON Chromaticity Control
  - Reduce the Chromaticity
    - Shielding of the F0 Lambertsons
      - Reduces the transverse impedance of the TEV
    - Re-wiring of the TEV octupole circuits
      - Gives more Landau damping
  - Reduce the differential chromaticity
    - Re-wiring of the TEV octupole circuits

- ## Better TEV Helices
  - Optimized helices at 150 GeV - designed – waiting for study time
    - Increases the separation of closest near misses without increasing overall separation
 - Bigger and optimized helices up the ramp - installed – waiting for 2nd round of optimization

TEVATRON Reliability

- Our highest luminosities were obtained by shooting from large stacks

> These large stacks were obtained by stacking for a long time because the previous store lasted a long time

> Our desire is to run long stores and stack big.

> However, our average store length is limited by equipment failure

TEVATRON Store Reliability

Period between 5/1/02 thru 9/8/03

334 stores

110 stores ended in failure
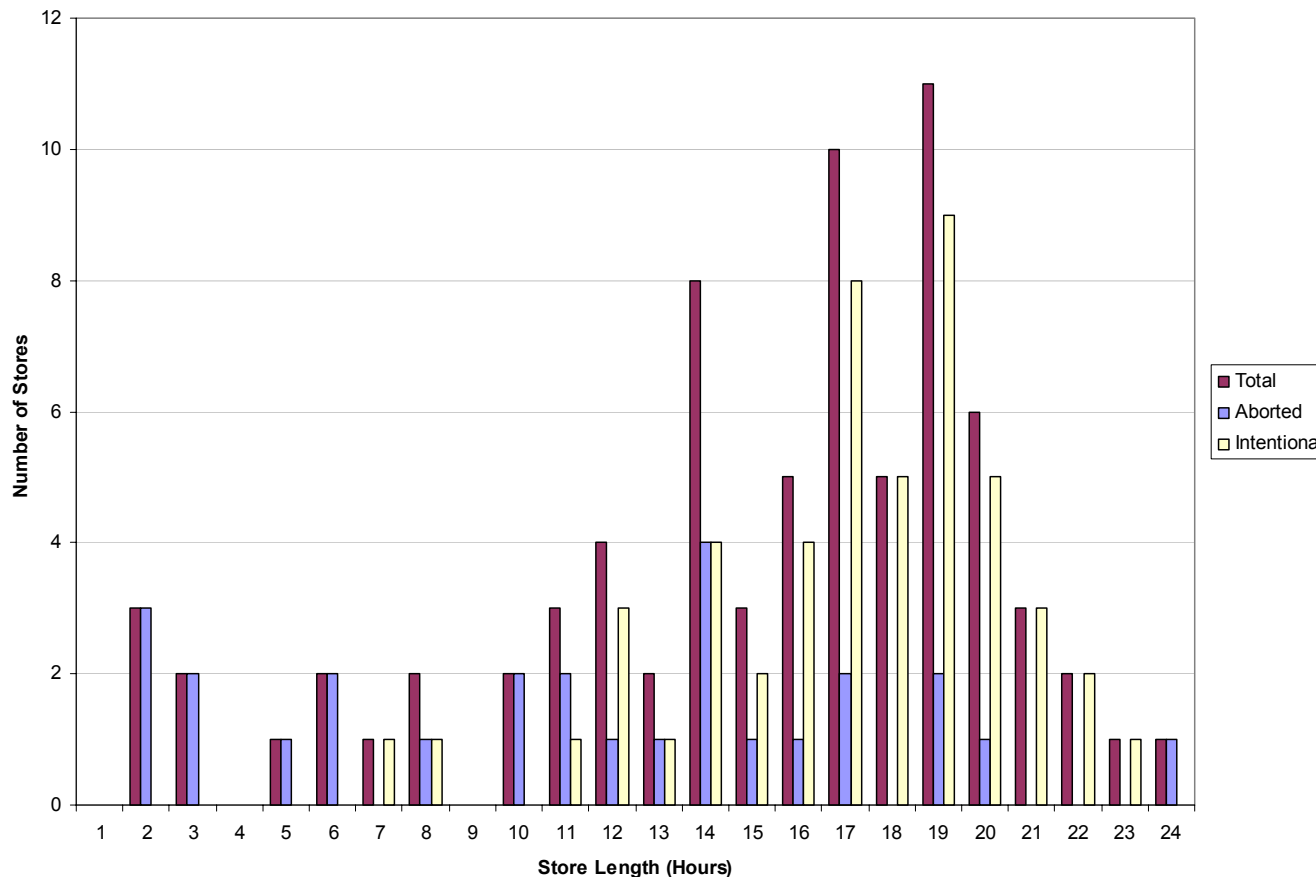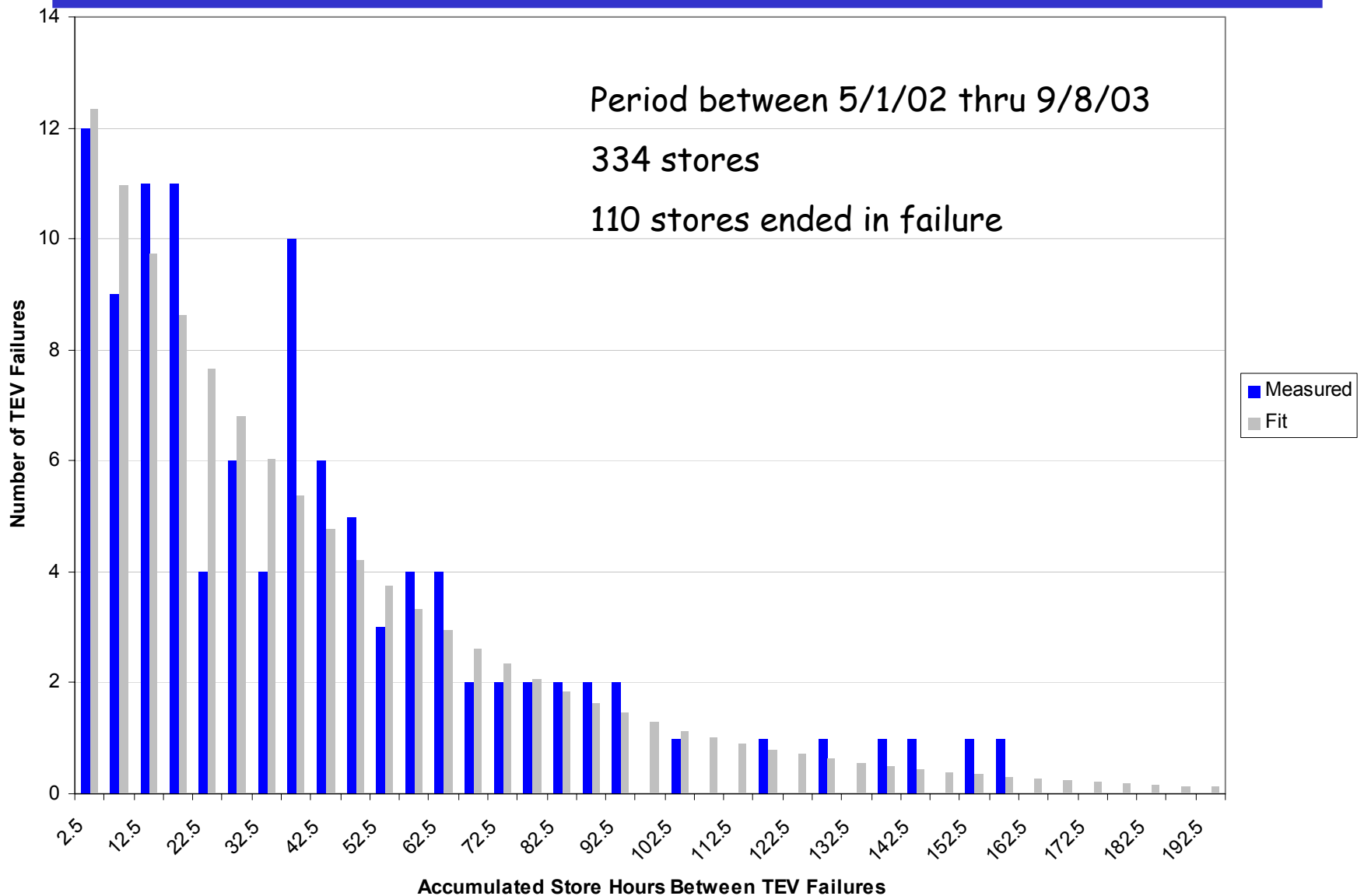
TEVATRON Store Reliability

- A TEV failure is independent of the time in the store (exponential distribution)
  - The mean number of store hours between failures is 42 hours
  - 42 hours translates to a TEV reliability of 97.6% per hour
    - The probability that the TEV will remain at up for the next hour is 97.6%
- A TEV Reliability of 97.6% predicts that:
  - 1 out of every 4 stores will end in failure if our target store duration is 12 hours
  - 1 out of every 3 stores will end in failure if our target store duration is 17 hours
- Increasing the reliability by 1% will, on average, require the doubling of the lifetime of TEV components

TEVATRON Shot Reliability
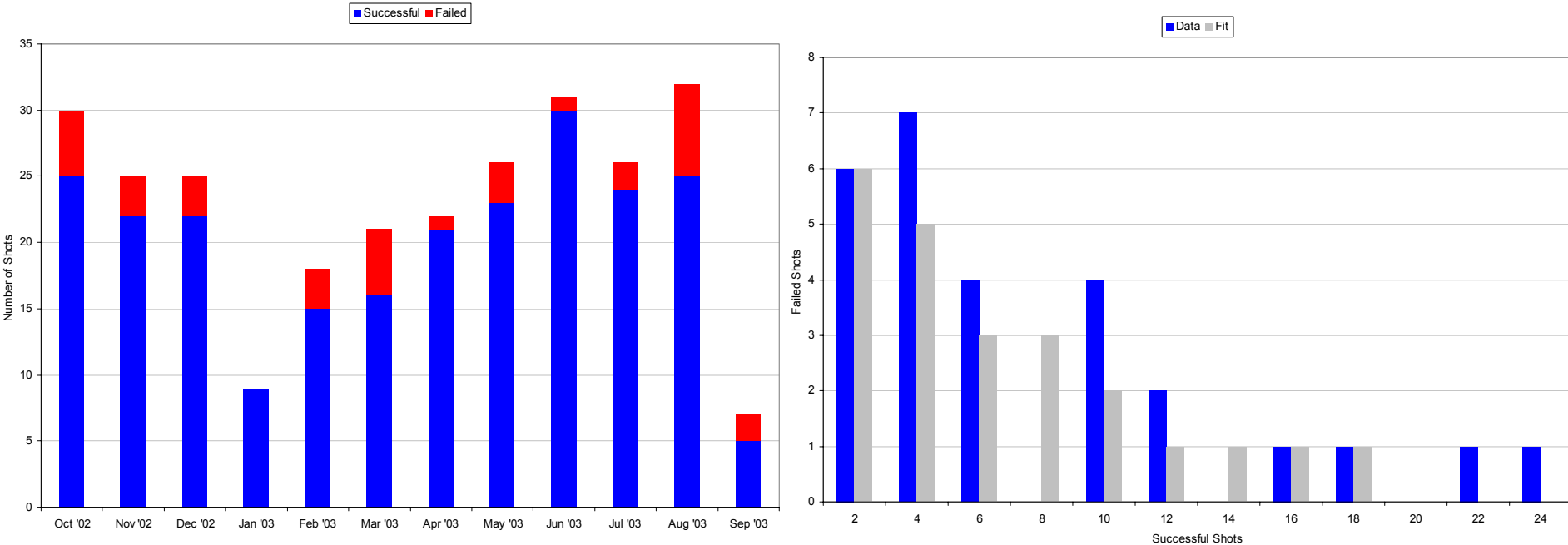
- The number of shots that made it successfully to HEP in FY03 is 237 out of 272 attempted (87%)
- The mean number of successful shots between failed shots is 7
  - ➢ The reliability of TEV shots is 85% per shot

TEV Downtime Since 1/1/03

- **The length of TEV downtime has an exponential distribution with a mean length of down time equal to 2.2 hours**
 - ➢ This corresponds to a probability of remaining down at 36.5% per hour

Length of downtime (hours)
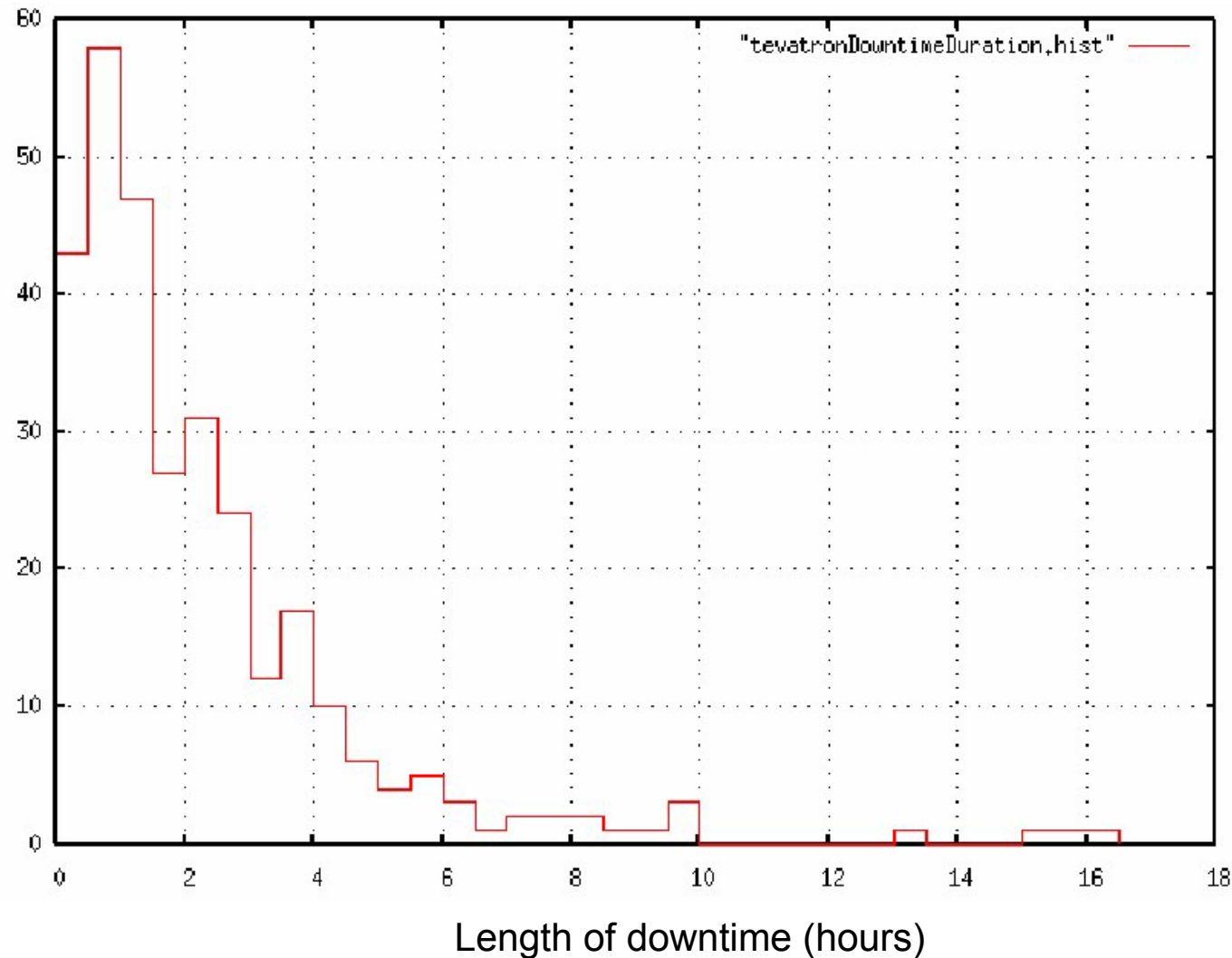
TEVATRON Reproducibility

- ## The TEVATRON is a finicky machine to operate.

- ## We have identified a number of issues that might make the TEVATRON much easier to operate

  - ➢ TEV diagnostics
  - ➢ TEV coupling
  - ➢ TEV alignment

- ## There is a plan to align the TEVATRON

  - ➢ Install a new alignment network (this shutdown)
  - ➢ Reduce the coupling by shimming the smart-bolts in ~100 TEV dipoles (this shutdown)
  - ➢ Remove the largest magnet rolls
    - • Warm or cold (this shutdown) **?**
  - ➢ Re-align the TEV magnets where needed

Pbar Production

- Because our <u>average</u> store length is limited by equipment failure:
  - ➢ The only way to increase the luminosity significantly in FY04 is to increase the stacking rate.
  - ➢ The Pbar stacking rate is limited between "cooling" cycle time
- Pbar Cooling Cycle Projects
  - ➢ Debuncher Momentum Cooling Notch Filter Equalizers
  - ➢ New Stacktail BAW filters
  - ➢ Improved Stacktail crossover
  - ➢ Main Injector Beam loading compensation through the entire acceleration ramp
 - ➢ Main Injector Longitudinal Dampers

Pbar Stacking Rate
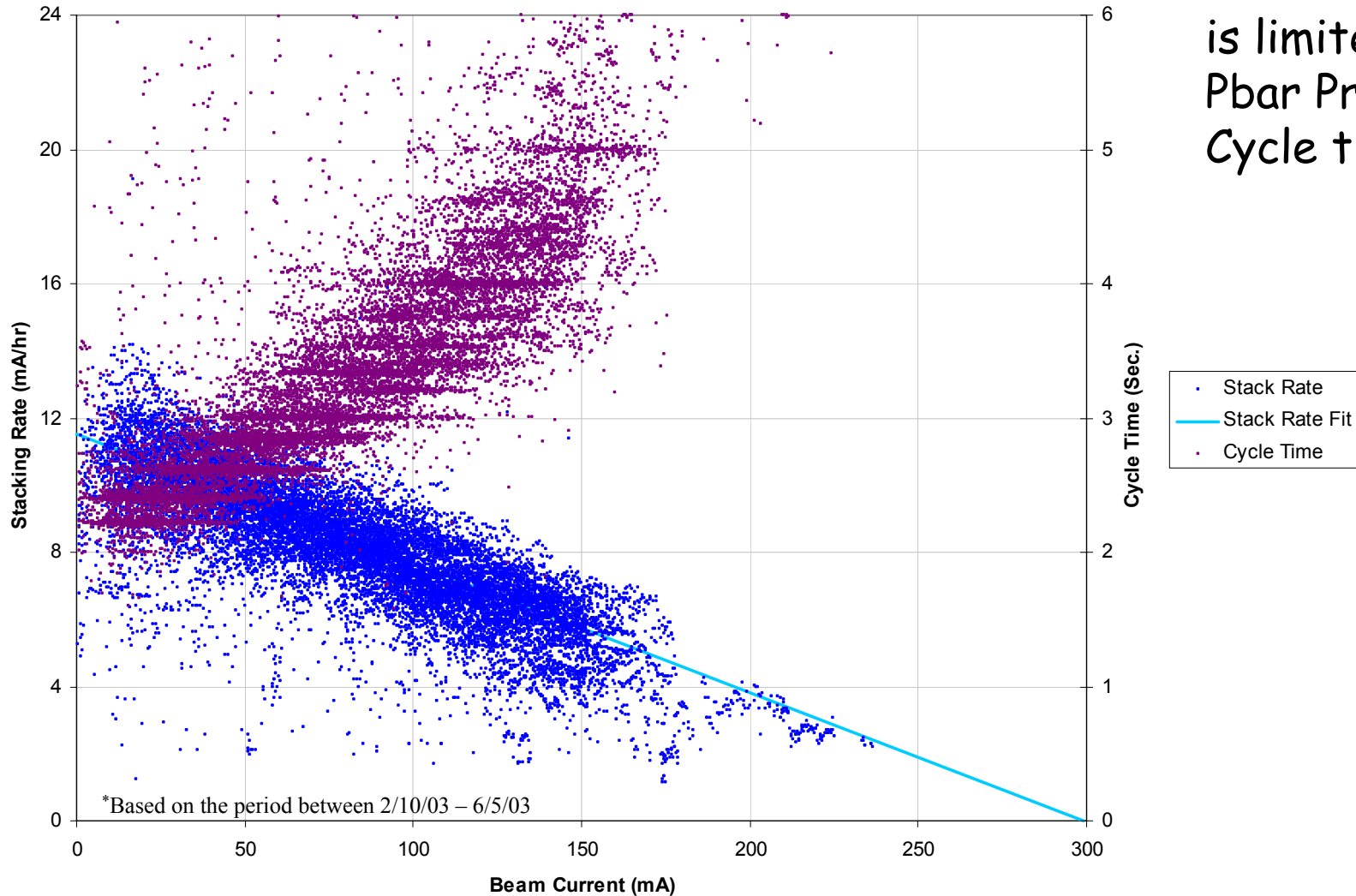
- The stacking rate is limited by the Pbar Production Cycle time

*Based on the period between 2/10/03 – 6/5/03

Why is the Cycle Time so Slow?

- Beam must be cleared off the Stacktail deposition orbit before next beam pulse.

  ➢ The more gain the Stacktail has, the faster the pulse will move.

Accumulator Longitudinal Spectrum
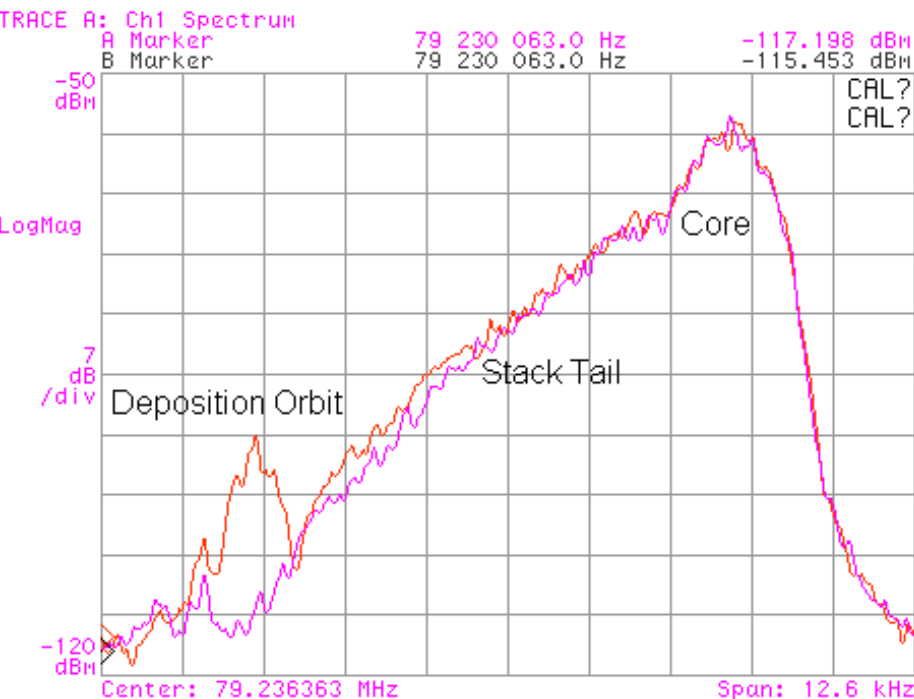
➢ The Stacktail gain is limited by
  • System instabilities between the core beam and the injected beam
  • Transverse heating of the Stacktail on the core

➢ As the stack gets larger
  • The instability feedback path grows stronger
  • The core transverse cooling gain is reduced

➢ The gain of the Stacktail must be turned down to compensate

➢ The cycle time must increase for the lower Stacktail gain

- For a given Stacktail gain, the larger the momentum spread of the injected pulse, the longer it takes to clear the pulse from the Stacktail Deposition orbit.

  ➢ The momentum spread coming from the Debuncher is too large.
    • Bunch length on target
    • Debuncher Cooling rate
   • Debuncher asymptotic momentum

Debuncher Momentum Cooling

- Reducing the Debuncher Momentum Cooling Notch filter dispersion by 33% will permit the zero stack cycle time to be lowered from 2.4 sec to 1.7 sec
  - ➢ First iteration complete
 - ➢ Second iteration to be installed this shutdown
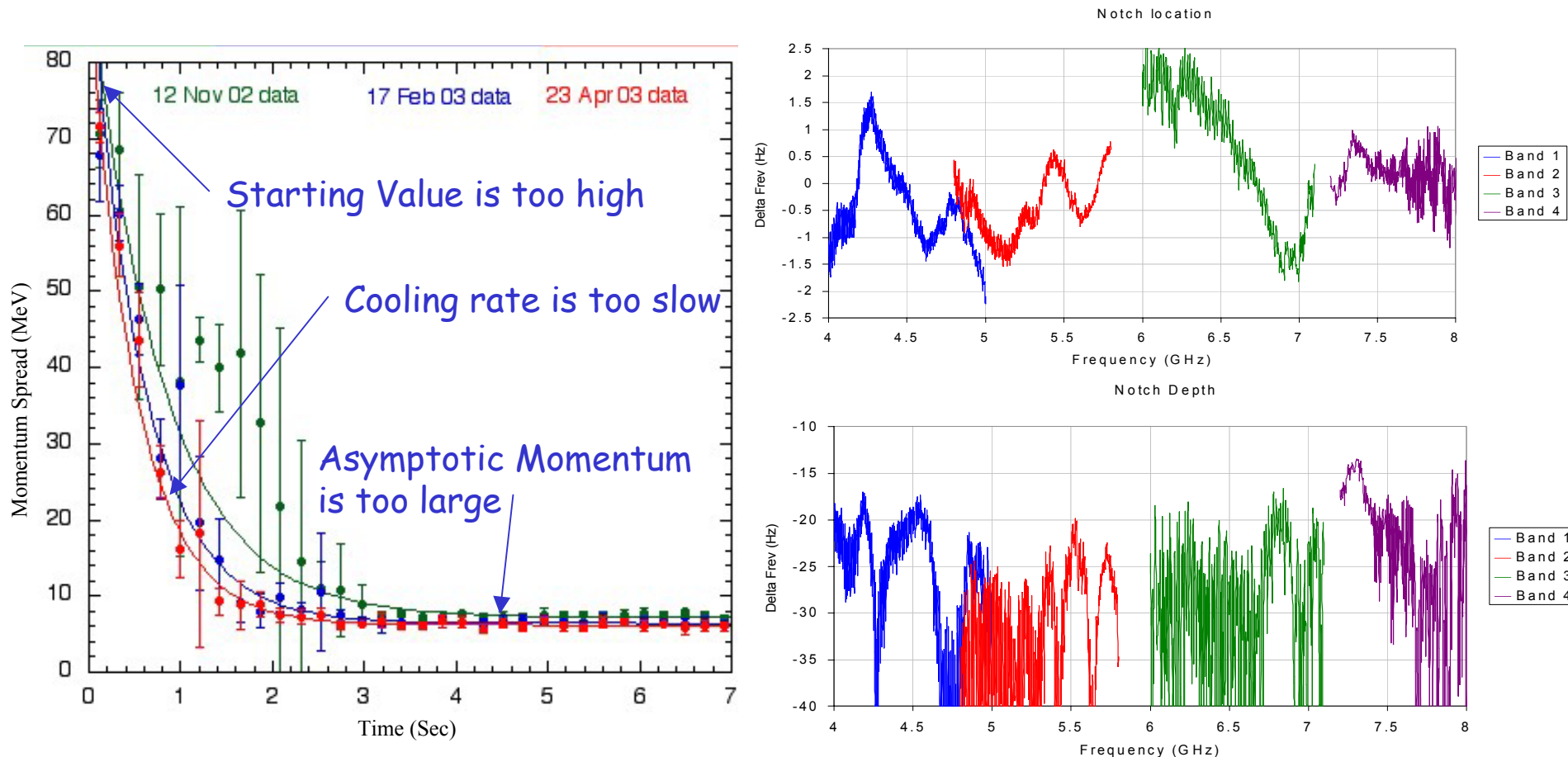
Improvements to the Stacktail

- Faster Cooling by extending lower end of band from 2.2 GHz to 1.7 GHz using new BAW filters (to be installed this shutdown)
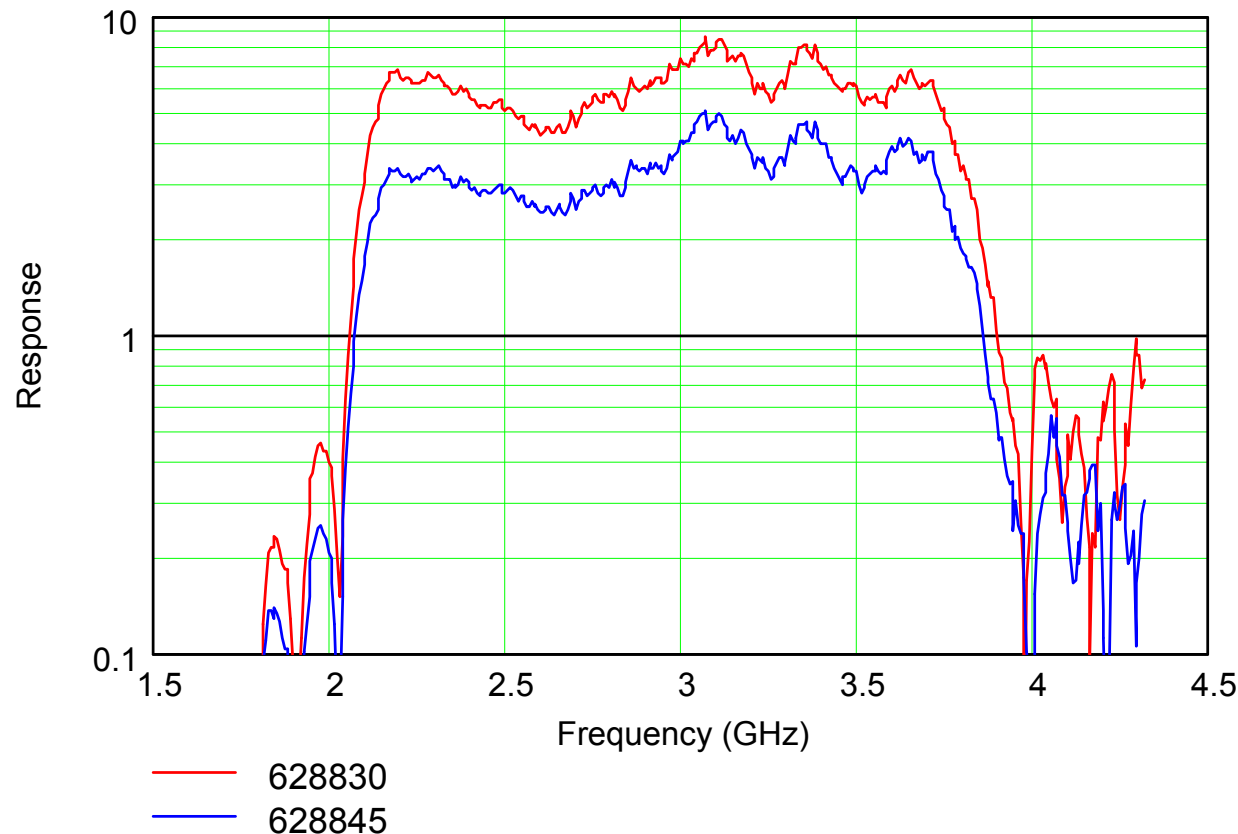
Improvements to the Stacktail

- Increase system stability by providing a better phase crossover
  - Beam transfer function measurements already done
  - Requires more analysis
  - Requires minor hardware changes
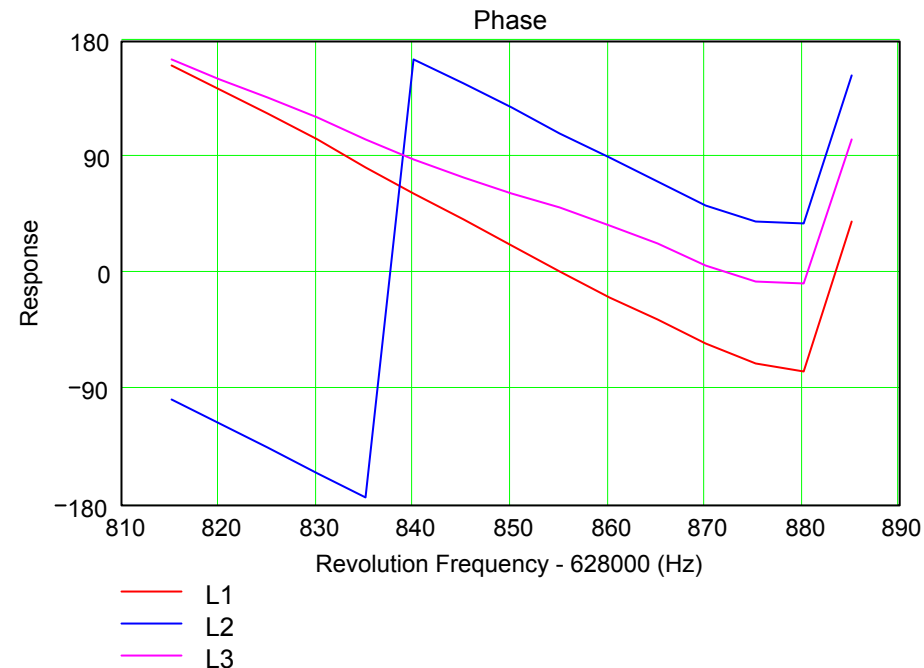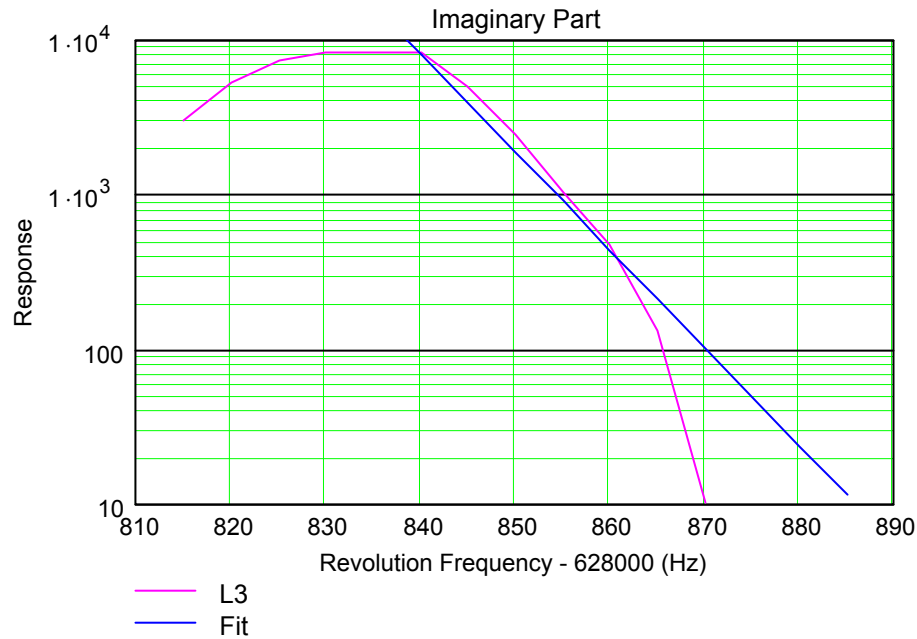
Reduce Bunch Length on the Pbar Production Target

- There is a very large longitudinal emittance blow up on the Pbar Production cycles in the Main Injector

- Effective bunch length on target is over 2 nS
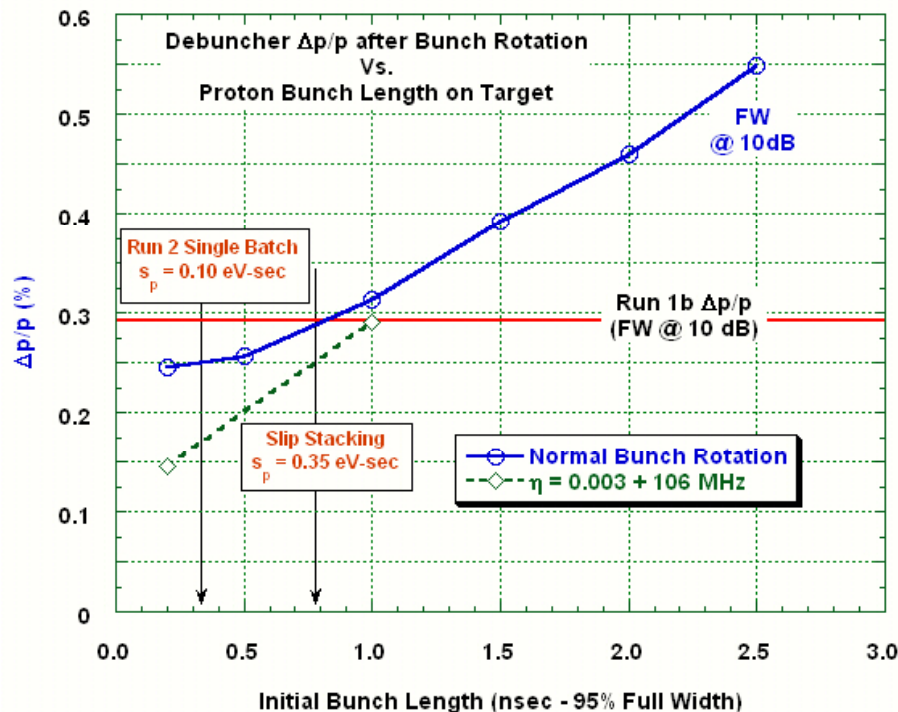
- Main Injector Longitudinal Emittance control projects
  - Beam loading compensation through the entire acceleration ramp
    - Beam loading compensation is a well defined project for the Run II Upgrades
    - Beam loading already commissioned for discrete points on the ramp
    - Study time and small changes in hardware required
  - Bunch by Bunch longitudinal dampers
    - Low level electronics built
    - Cavities to be installed this shutdown
    - System to be commissioned in early FY04

Luminosity Parameters

Luminosity Parameters			
Phase	FY03	FY04	
Initial Luminosity	37.9	74.9	$x10^{30}cm^{-2}sec^{-1}$
Average Luminosity	20.7	44.4	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per week	6.4	13.7	pb^{-1}
Integrated Luminosity per store	1.1	2.4	pb^{-1}
Number of stores per week	5.7	5.7	
Average Store Hours per Week	85	85	Hours
Store Length	15	15	Hours
Store Lifetime	11.0	13.0	Hours
HEP Up Time per Week	98	98	Hours
Good Week Ratio	1	1	
Shot Setup Time	2.2	2.2	Hours
	FY03	RED	

TEV Helices

TEVATRON Parameters

TEVATRON Parameters			
Phase	FY03	FY04	
Number of Protons per bunch	250	260	$\times 10^9$
Number of Pbars per bunch	24.9	37.6	$\times 10^9$
Proton Emittance	32	29	π-mm-mrad
Pbar Emittance	16	13	π-mm-mrad
σ_{proton}	0.525	0.500	meters
σ_{pbar}	0.525	0.500	meters
BetaIP	40	35	cm
Transfer Eff. To Low Beta	0.73	0.8	
	FY03	RED	

Using SBD Calibration

Back Calculated Emittances

F0 Lambertson

TEV Injection Matching

TEV Injection Coupling

TEV Helices

MI Long. Dampers

TEV Chromaticity control

Antiproton Production Parameters

Antiproton Parameters			
Phase	FY03	FY04	
Zero Stack Stacking Rate	11.3	18.0	$\times 10^{10}$/hour
Average Stacking Rate	8.2	11.3	$\times 10^{10}$/hour
Stack Size transferred	122.6	169.1	$\times 10^{10}$
Stack to Low Beta	89.5	135.3	$\times 10^{10}$
Pbar Production	15.0	17.0	$\times 10^{-6}$
Protons on Target	5	5	$\times 10^{12}$
Pbar cycle time	2.4	1.7	Secs.
Pbar up time fraction	1	1	
Initial Stack Size	15	15	$\times 10^{10}$
Stack Size at 1/2 Stacking Rate	150	150	$\times 10^{10}$
	FY03	**RED**	

Debuncher Quad Stands

Debuncher filters

Stacktail filters

Stacktail phase crossover

MI Long. Dampers

Operations

Startup Strategy

- Establish luminosity as quickly as possible
  - ➢ Startup tasks will focus on accelerator fundamentals
    - Orbits
    - Tunes
    - Chromaticity
    - Transfer mechanics
  - ➢ Advanced commissioning of the accelerator upgrades installed during this shutdown will await the return of routine study periods <u>after luminosity is established</u>.

FY04 Study Strategy

- **FY04 Parasitic Study Strategy**
  - Recycler "Pbar Tax"
    - 25% of the Pbar stacking time line will go to Recycler commissioning
    - Uses of the tax: MI Access time, Proton events, Pbar transfers
  - Present 80% Stack size / 20% Time-line strategy
- **FY04 Dedicated Study Strategy**
  - A study period would begin only if the previous 14 days contained 140 hours of store time.
  - Study periods would occur twice a week.
  - Study periods will be short (8-12 hours)
  - There would be at least two stores between each study period.
  - Studies would be blocked according to themes.
  - At the end of the study block (or theme) a short write-up (TEV Note or Pbar Note) describing the results of the studies would be expected.
- Maintenance studies would occur at the discretion of the Run Coordinator.

Shot Strategy

- **What is the best strategy for ending a store?**
  - ➤ How long should we run the stores?
  - ➤ What stack size should we shoot from
- **What is the best strategy for recovering from TEV failure or a lost Pbar Stack?**
  - ➤ What is the minimum stack we should shoot from.
- **When is the best time to do studies?**
- **We are re-developing a Monte-Carlo model of the TEVATRON Complex**
  - ➤ Will incorporate a realistic model of the TEVATRON based on realistic parameters obtained from SDA
  - ➤ Will model the inherent randomness of the Collider Complex
    - Downtime (based on SDA)
    - Variations on all realistic parameters (based on SDA)

Simulation of a Typical 2 Week Stacking Period
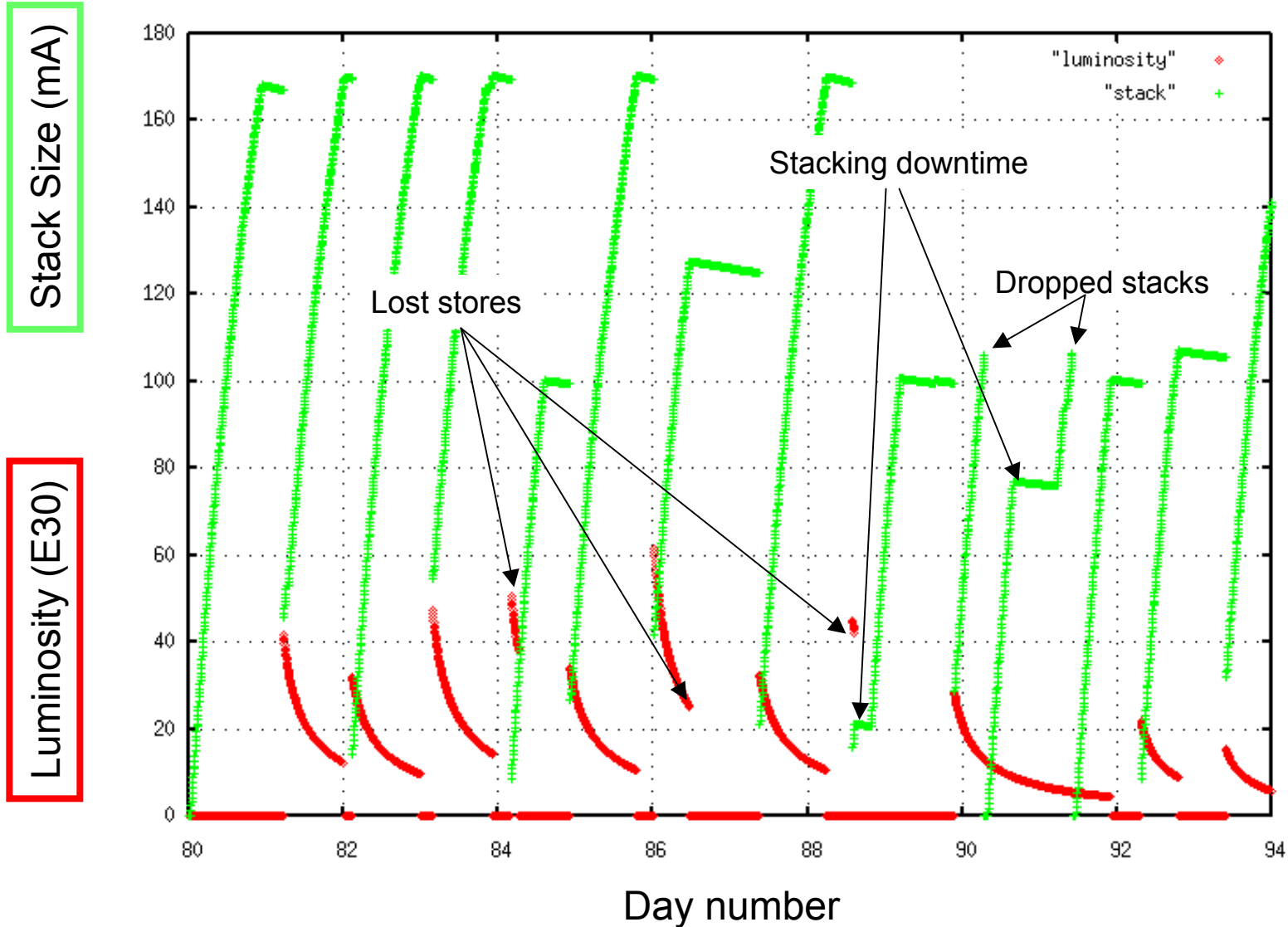
# Algorithms for Ending a Store

- ## Target Crossings
  - Stack Size
  - Store Duration
  - Integrated Luminosity
  - Minimum Instantaneous Luminosity

- ## Luminosity Potential
  - Comparison of "Expected" instantaneous luminosity and present instantaneous luminosity
    - When the <u>ratio</u> between the expected luminosity and the current luminosity exceed some constant, V.
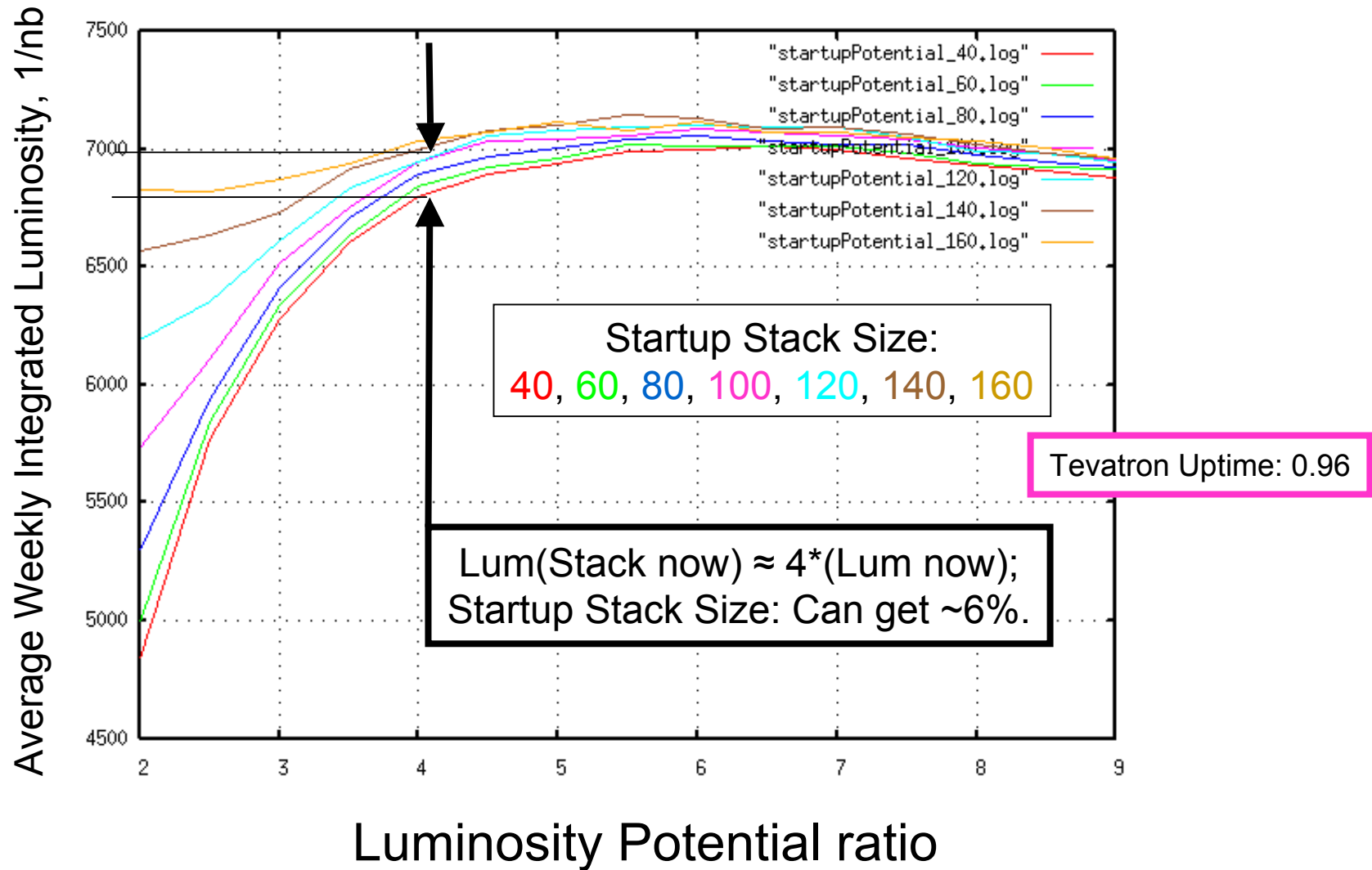   - When the <u>difference</u> exceeds constant, L.
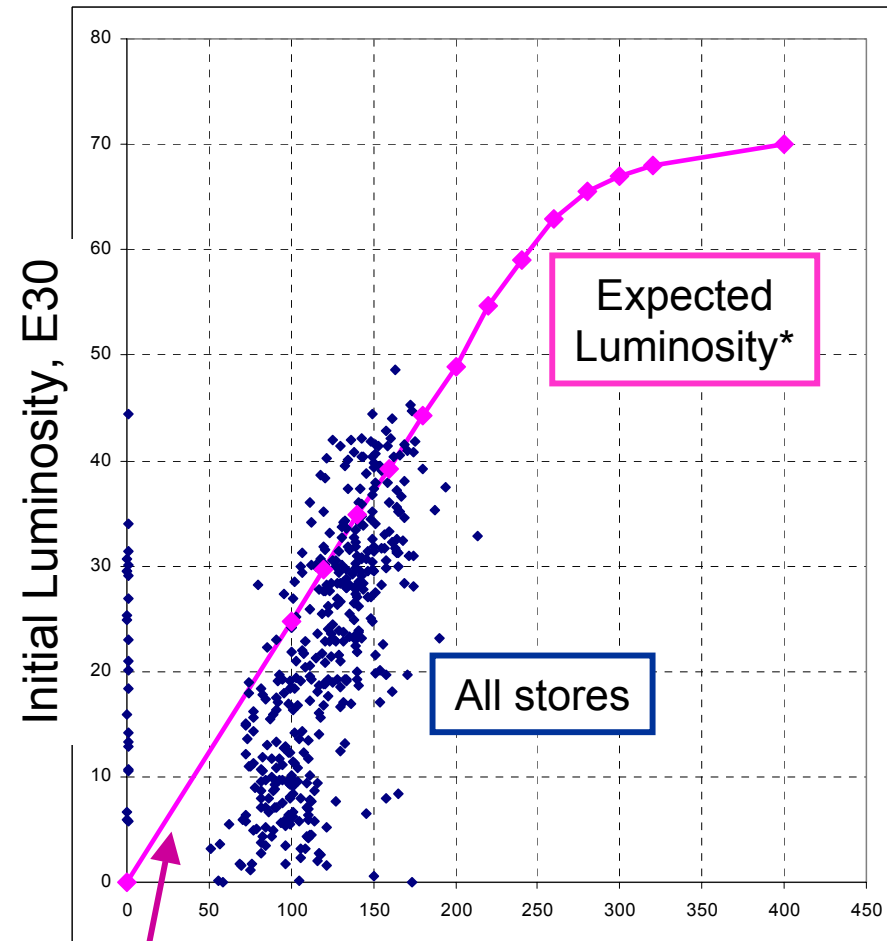
Generated by the model; error bars (σ) ≈ 20%

Needs more confirmation from SDA

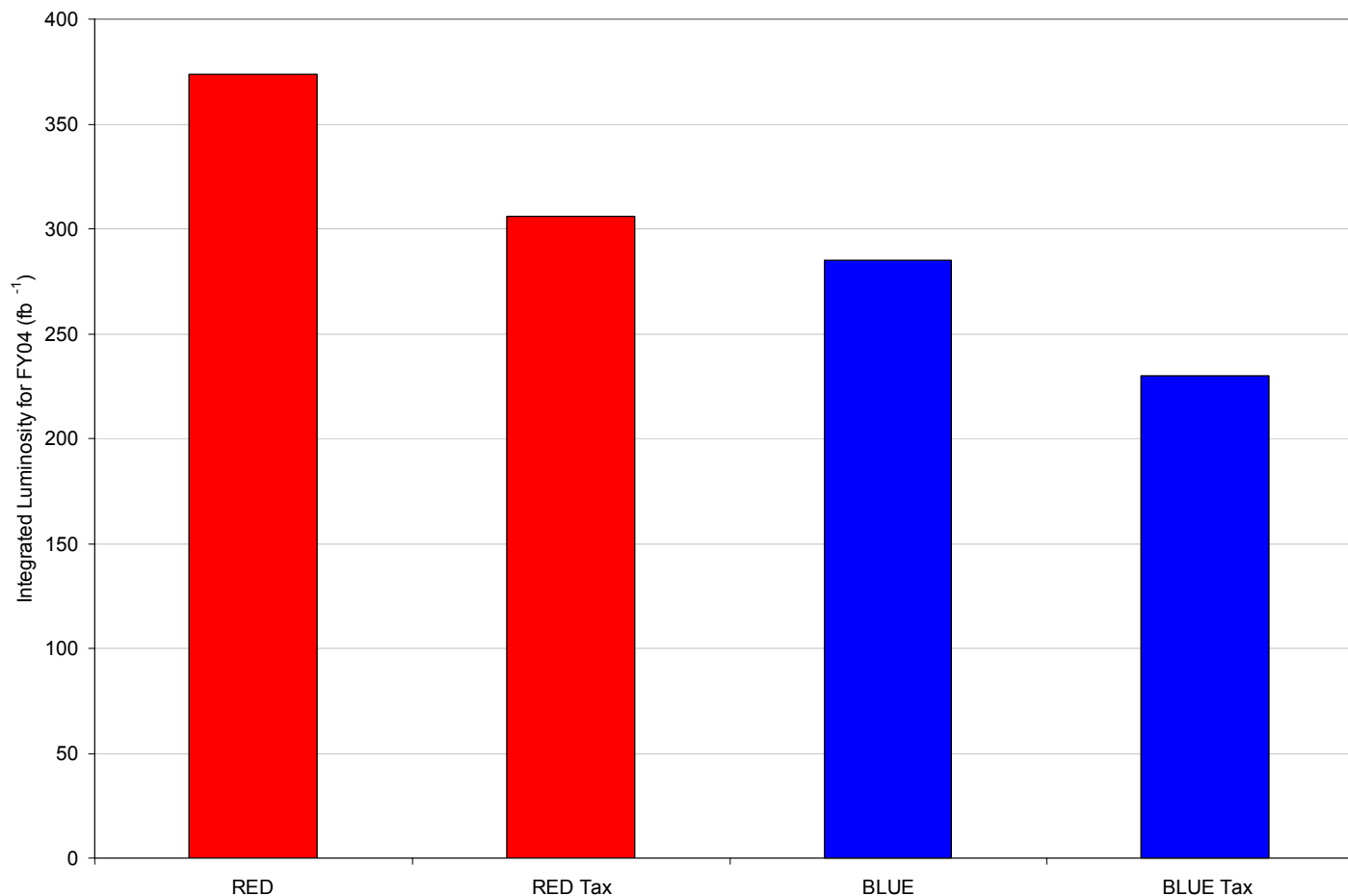# Target Stack Size and Recovery from TEV Failure
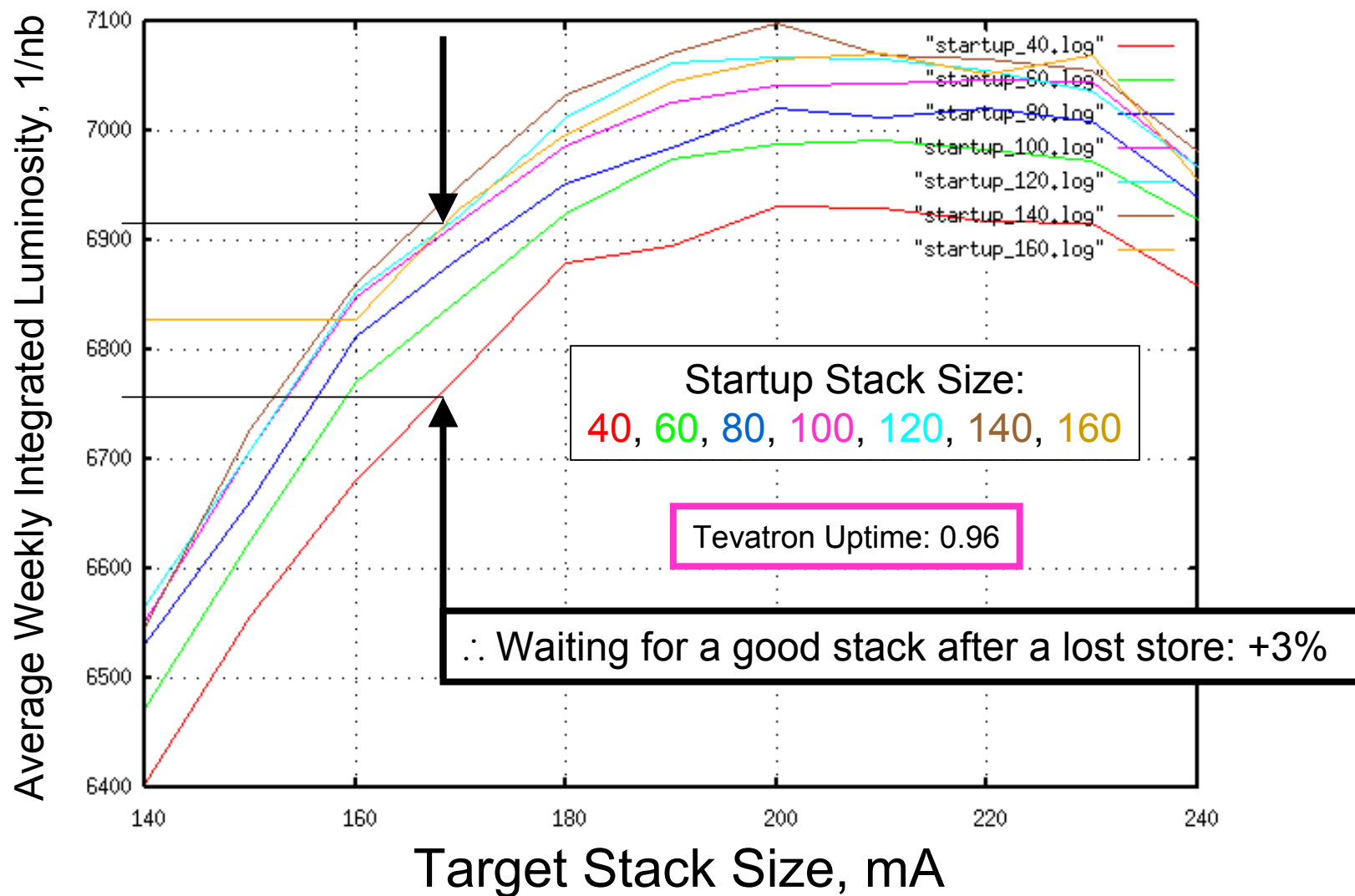
Example of Startup Stack Size and Luminosity Potential Ratio

FY04 Luminosity Parameters

FY04 Integrated Luminosity

Fiscal Year	RED	RED Tax	BLUE	BLUE Tax	
FY04	373	306	285	230	pb^{-1}

Luminosity Parameters

Phase	Luminosity Parameters					
	FY03	FY04	FY04	FY04	FY04	
Initial Luminosity	37.9	74.9	61.9	53.4	43.3	$\times10^{30}cm^{-2}sec^{-1}$
Average Luminosity	20.7	44.4	36.8	30.5	24.7	$\times10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per week	6.4	13.7	11.3	9.2	7.4	pb^{-1}
Integrated Luminosity per store	1.1	2.4	2.0	1.6	1.3	pb^{-1}
Number of stores per week	5.7	5.7	5.7	5.6	5.6	
Average Store Hours per Week	85	85	85	84	84	Hours
Store Length	15	15	15	15	15	Hours
Store Lifetime	11.0	13.0	13.0	12.0	12.0	Hours
HEP Up Time per Week	98	98	98	96	96	Hours
Good Week Ratio	1	1	1	1	1	
Shot Setup Time	2.2	2.2	2.2	2.2	2.2	Hours
	FY03	RED	RED TAX	BLUE	BLUE Tax	

TEVATRON Parameters

Phase	TEVATRON Parameters					
	FY03	FY04	FY04	FY04	FY04	
Number of Protons per bunch	250	260	260	260	260	$\times 10^{9}$
Number of Pbars per bunch	24.9	37.6	31.1	30.3	24.5	$\times 10^{9}$
Proton Emittance	32	29	29	31	31	π-mm-mrad
Pbar Emittance	16	13	13	15	15	π-mm-mrad
σ_{proton}	0.525	0.500	0.500	0.500	0.500	meters
σ_{pbar}	0.525	0.500	0.500	0.500	0.500	meters
BetaIP	40	35	35	37	37	cm
Transfer Eff. To Low Beta	0.73	0.8	0.8	0.77	0.77	
	FY03	RED	RED TAX	BLUE	BLUE Tax	

Using SBD Calibration

Back Calculated Emittances

Antiproton Parameters

| Phase	Antiproton Parameters					
	FY03	FY04	FY04	FY04	FY04	
Zero Stack Stacking Rate	11.3	18.0	18.0	13.7	13.7	$\times 10^{10}$/hour
Average Stacking Rate	8.2	11.3	9.3	9.4	7.6	$\times 10^{10}$/hour
Stack Size transferred	122.6	169.1	139.9	141.4	114.6	$\times 10^{10}$
Stack to Low Beta	89.5	135.3	111.9	108.9	88.2	$\times 10^{10}$
Pbar Production	15.0	17.0	17.0	16.0	16.0	$\times 10^{-6}$
Protons on Target	5	5	5	5	5	$\times 10^{12}$
Pbar cycle time	2.4	1.7	1.7	2.1	2.1	Secs.
Pbar up time fraction	1	1	0.75	1	0.75	
Initial Stack Size	15	15	15	15	15	$\times 10^{10}$
Stack Size at 1/2 Stacking Rate	150	150	150	150	150	$\times 10^{10}$
	FY03	RED	RED TAX	BLUE	BLUE Tax	
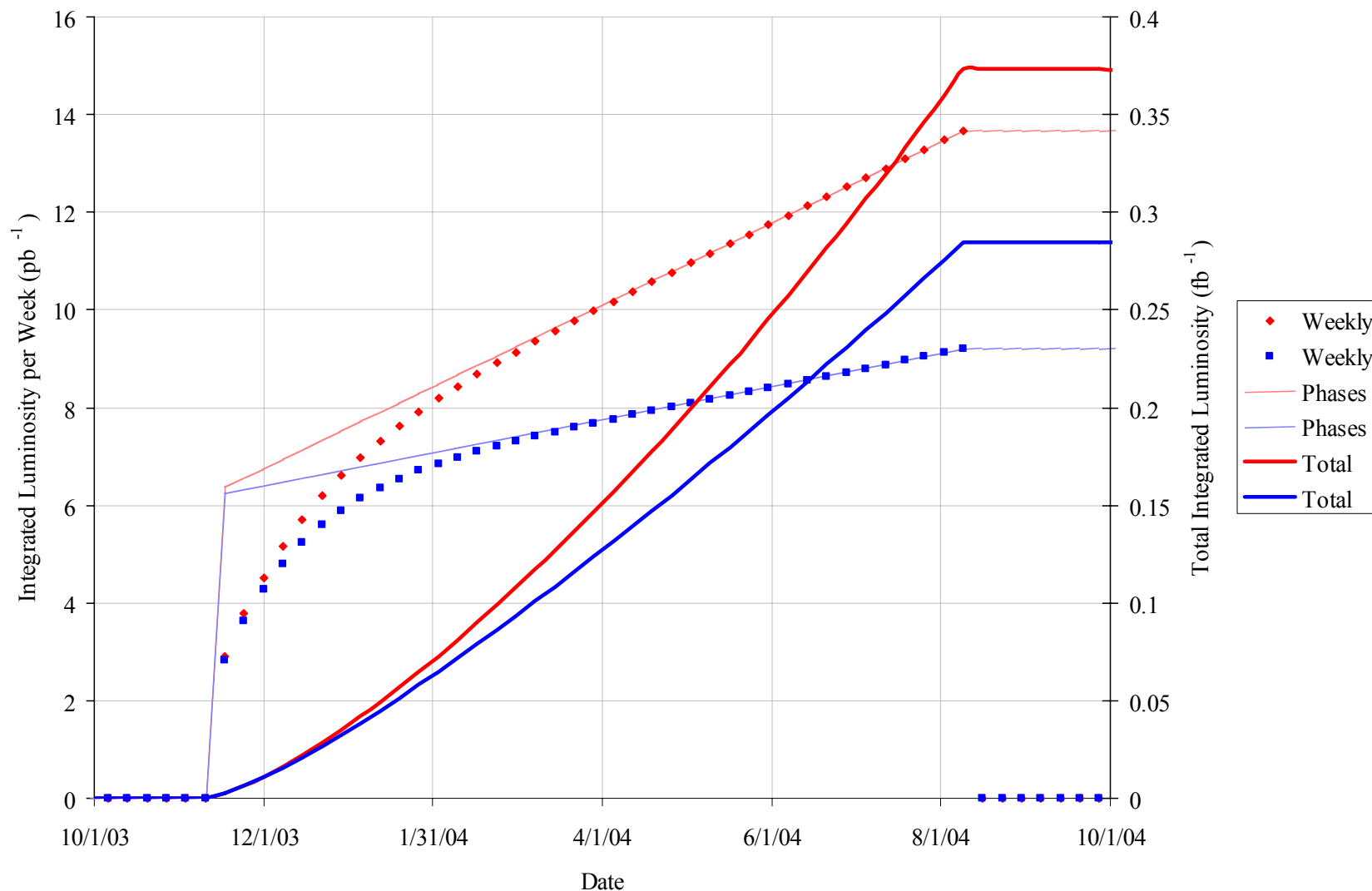
Integrated Luminosity per Week – with Pbar tax
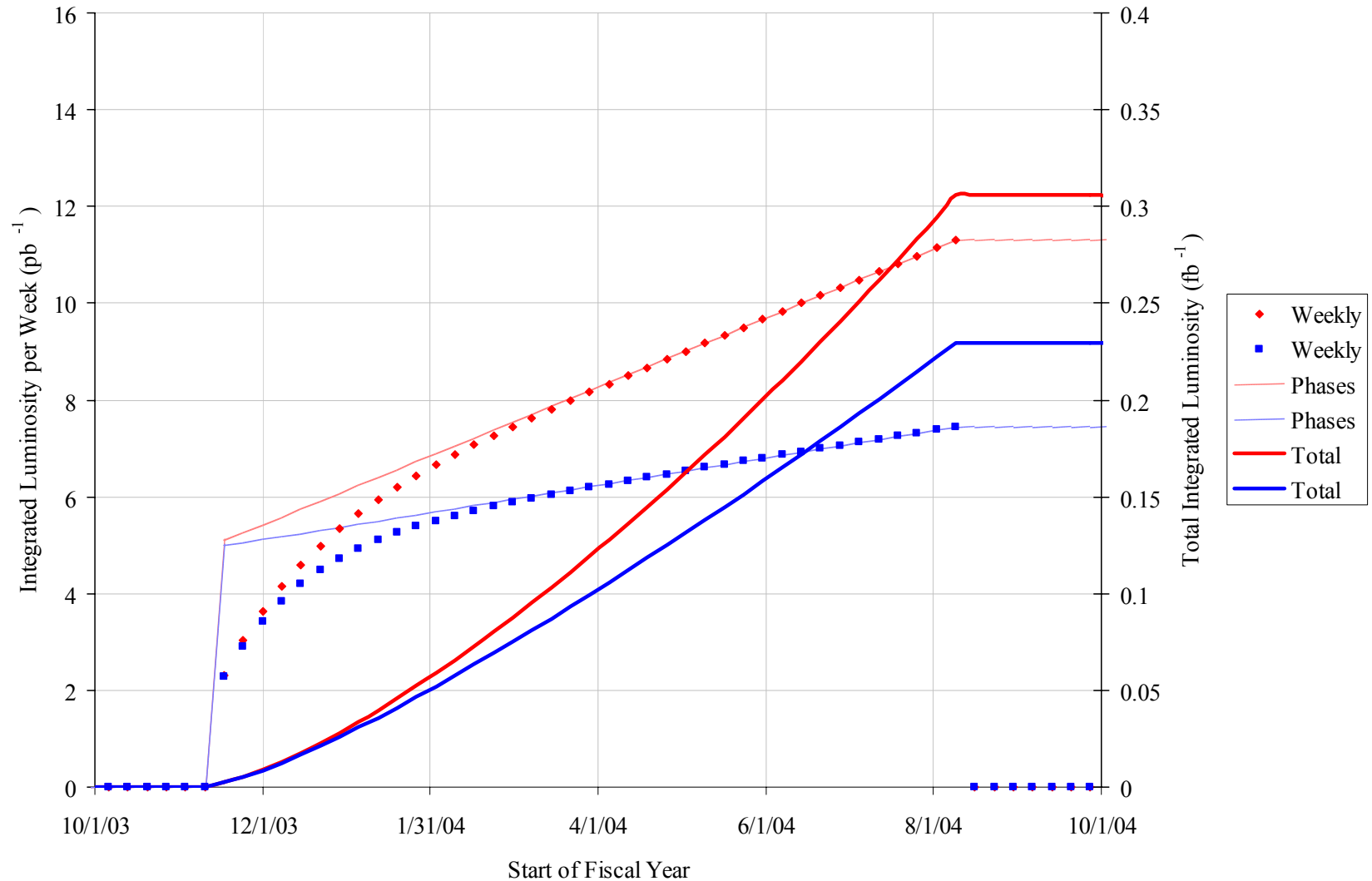
Peak Luminosity – no Pbar tax
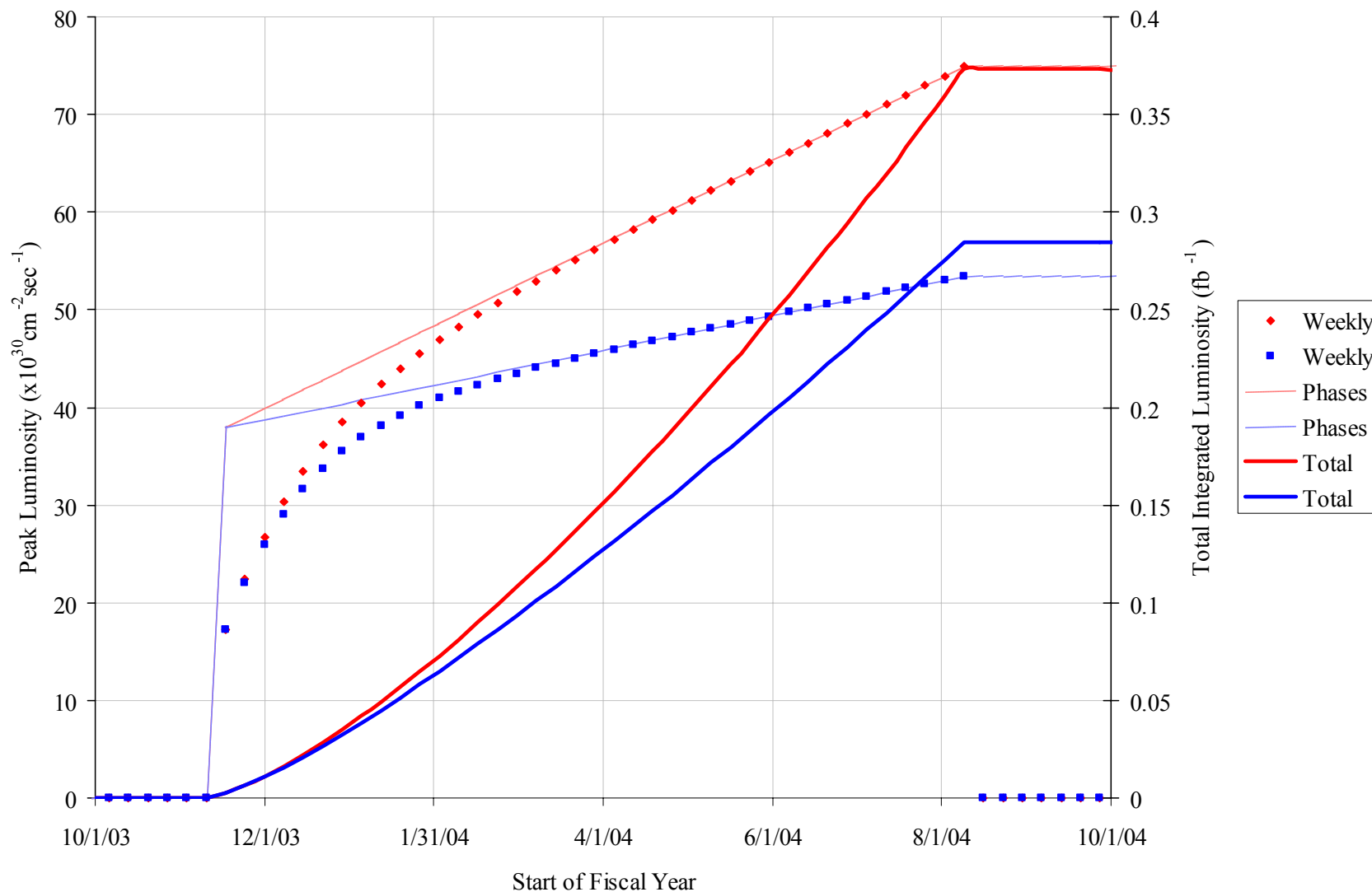
Peak Luminosity – Pbar tax
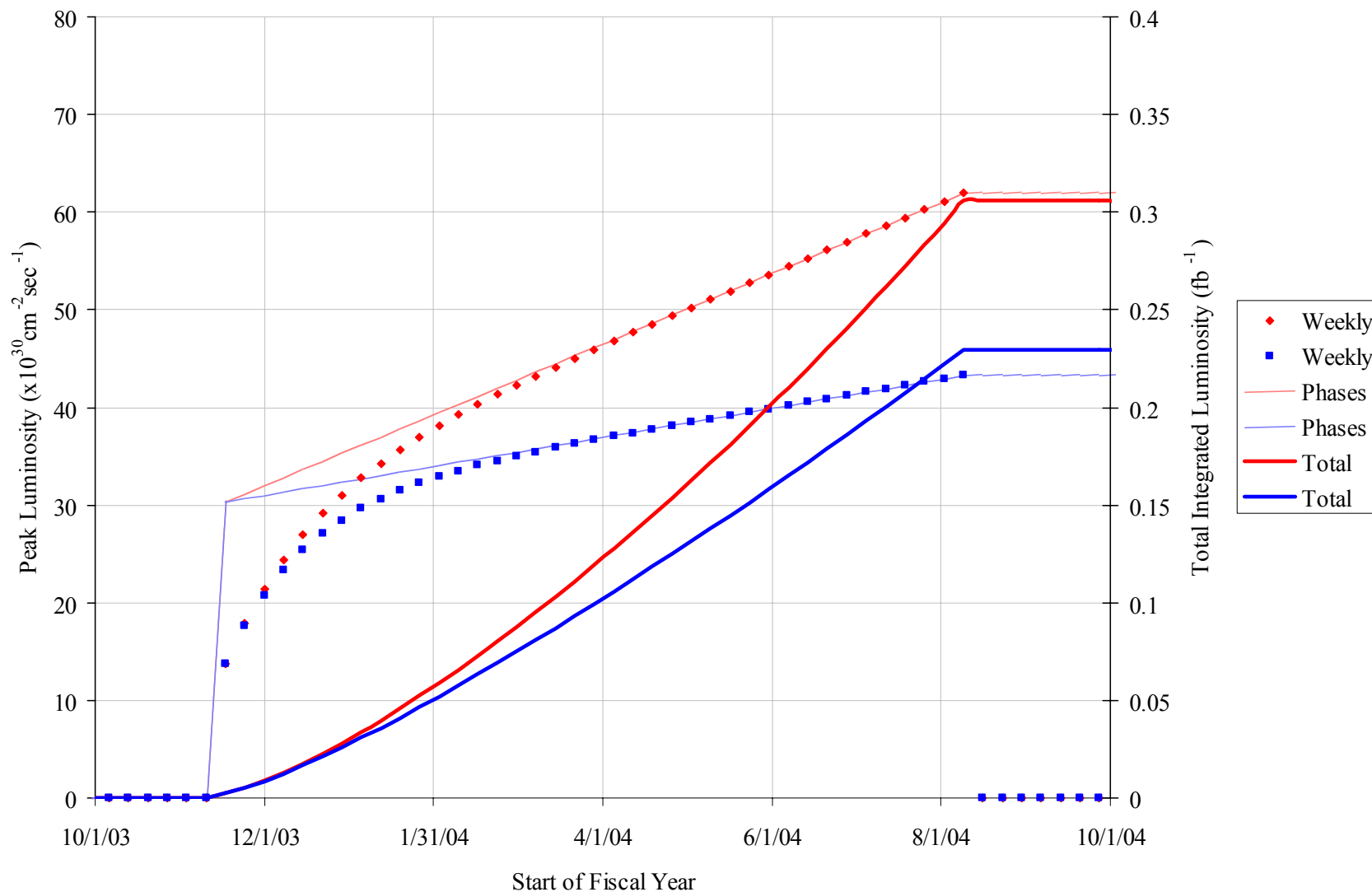
Summary

- In FY03, we focused on
  - Increasing the proton intensity (250×10^9/bunch)
  - Increasing the transmission efficiency of pbars to low beta (73%)
- Our goal in FY04 is to increase the potential for integrating luminosity by a factor of 2 over FY03. This increase will be done mainly by increasing:
  - Zero stack stacking rate
  - Transmission efficiency of pbars to low beta
- The vast majority of hardware needed to accomplish the FY04 goals will be installed by the end of this shutdown.
- The Collider is commissioned
  - We are in an operating phase with periodic upgrades to be installed during shutdowns.
  - With an integrated accelerator study philosophy and an operations model of the complex, we will balance
    - Integrating luminosity
    - Accelerator studies
    - Commissioning the Recycler